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Plate 4

Air Pump

Facing p. 197

Fig. I

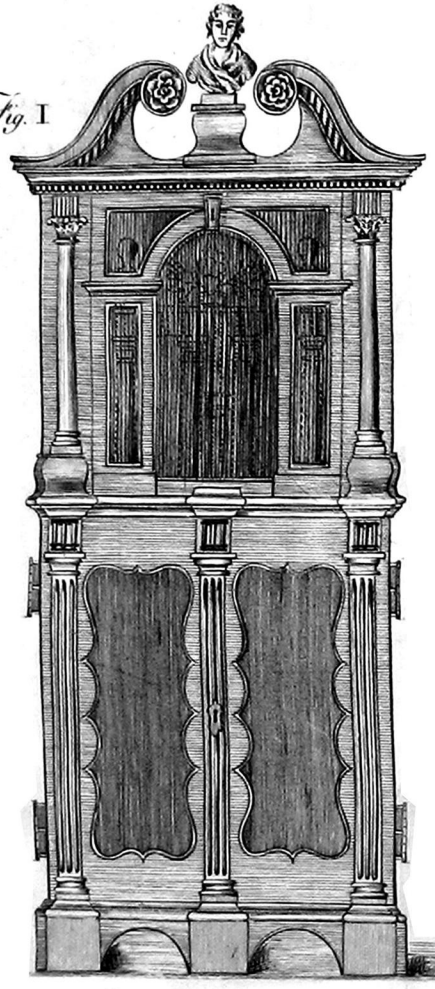

Fig. II

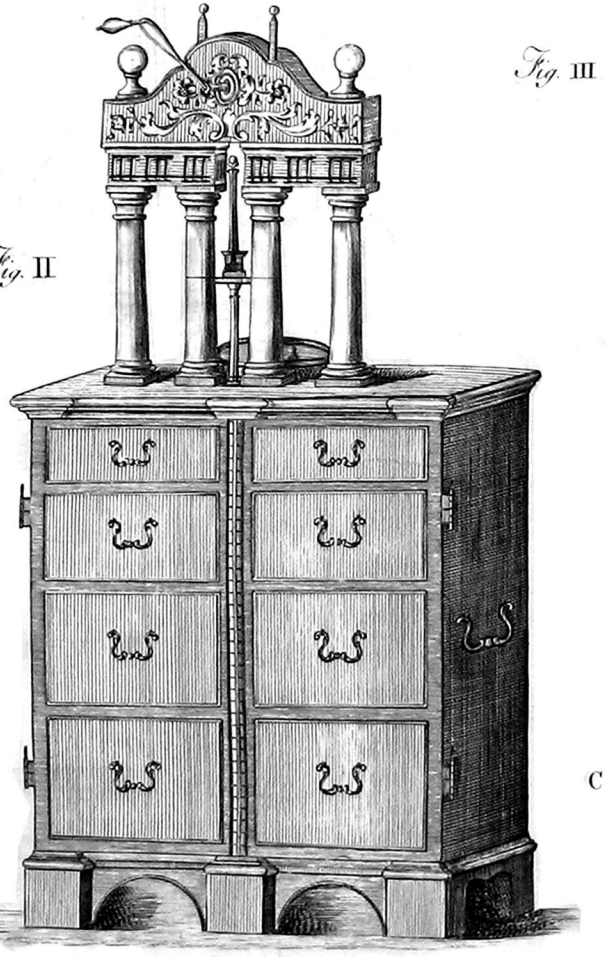

Fig. III

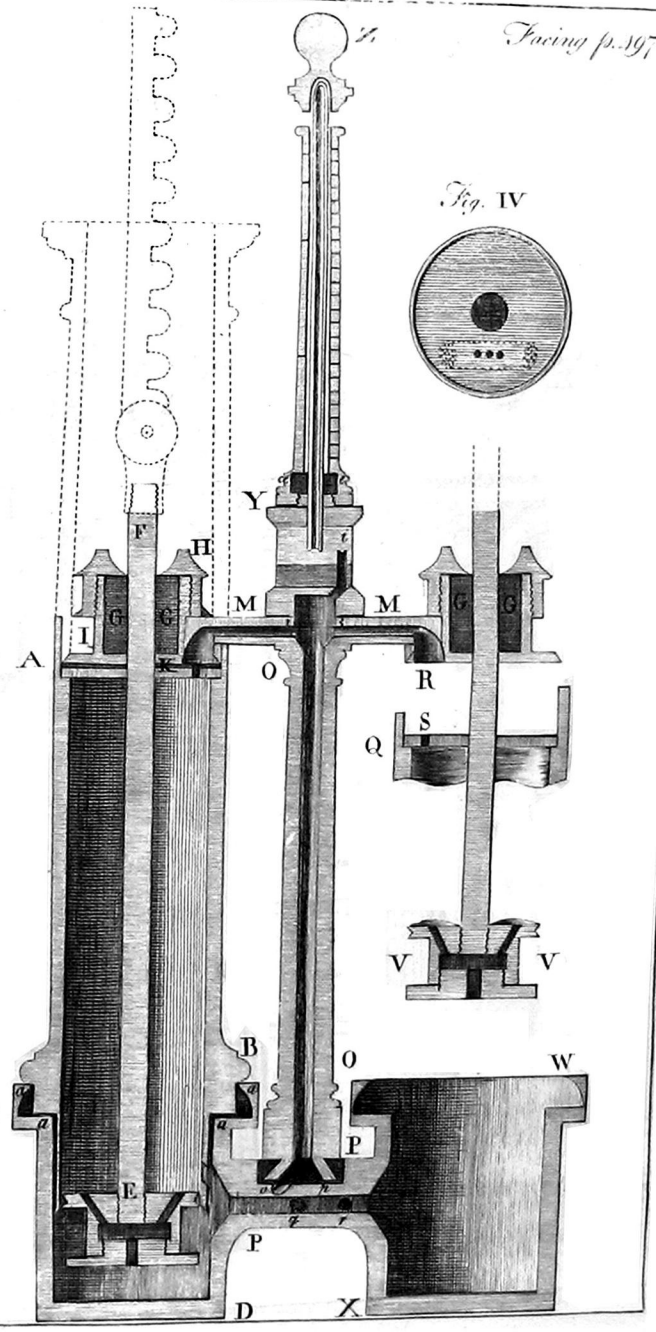

Fig. IV

XXVI. *An Account of an Air-Pump on a new Conſtruction; with ſome Obſervations on the common Air-Pump, and Mr.* SMEATON'S *improvement: In a Letter from the Rev.* JOHN PRINCE *to the Rev.* JOSEPH WILLARD, *Preſident of the Univerſity of* Cambridge.

Salem, Nov. 10, 1783.

REV. AND DEAR SIR,

AGREEABLE to your requeſt, I will endeavour to give you ſome account of the air-pump I have lately conſtructed, upon a plan different from any I have ever ſeen.

Reading the account of the ingenious Mr. *Smeaton's* air-pump, in vol. xlvii. of the Philoſophical Tranſactions, and the high recommendation of it by Dr. *Prieſtley*, in vol. lxiv. of the ſame work, I was deſirous of poſſeſſing one of that kind: but finding, by the Doctor's paper, they were not commonly made by the philoſophical inſtrument-makers in *London*, it induced me to attempt making one myſelf, with ſuch aſſiſtance as I could get here.

Before I had proceeded far, I thought Mr. *Smeaton's* pump might be improved, if not in its power of rarifying the air, at leſt in ſimplicity. With this in view, I have finiſhed mine. To ſhow the ground on which I have gone, it will be neceſſary to conſider the rationale of an air-pump, and make ſome obſervations on Mr. *Smeaton's*. It is well known that the valve at the bottom of the barrel of an air-pump is opened by the ſpring of the air acting againſt it underneath, when the weight of the air is removed from the top of the valve, by raiſing the piſton in the barrel. In order to remove this reſiſtance from the top of the valve moſt effectually, the piſton ſhould be made to fit very exactly to the valve-plate, when put down upon it: for if there be any ſpace between the bottom of the piſton and

valve, part of the air will be retained in it; and this air, even when the piſton is raiſed to the higheſt, will, by its expanſion, in ſome meaſure, obſtruct the opening of the valve. When the air in the receiver, or underneath the valve, is rarefied to an equal degree with the air contained in the barrel, (the piſton being drawn up to the higheſt) the valve can riſe no longer, becauſe the reſiſtance above is equal to the power below. The reſiſtance from this air, retained in the barrel, againſt the valve at the bottom, will be uniformly the ſame, when the piſton is at the ſame diſtance from it; becauſe the weight of the atmoſphere is continually preſſing on the piſton-valve, and will prevent the air below paſſing through it, while this air is rarer than the atmoſphere: and when the piſton is put down to the bottom of the barrel, it will not eſcape through the piſton, but only be compreſſed into the vacancy between the bottom of the piſton and the valve-plate at the bottom of the barrel, and be of equal denſity with the atmoſphere. Beſides the reſiſtance ariſing from this retained air, we muſt conſider the weight of the valve, its coheſion to the plate, occaſioned by the oil, and its being ſtretched tight over the hole, as increaſing the obſtruction; eſpecially when the ſpring of the air under the valve is much weakened by rarefaction. And if we take into the account the reſiſtance ariſing from theſe cauſes, the denſity of the air in the barrel, when compreſſed into the abovementioned vacancy, will be as much greater than the denſity of the atmoſphere above the piſton, as the addition of this reſiſtance; for this obſtruction belongs to the piſton-valve, as well as to the other. And ſo alſo, when this retained air is expanded, ſay one hundred times, by raiſing the piſton, the air in the receiver cannot be rarefied to the ſame degree, becauſe of this reſiſtance of the valve at the bottom of the barrel.

In

In order to produce a greater rarefaction of the air in the receiver than what the common pump will effect, the valves, where uſed, muſt be made to open eaſier, by removing, as far as poſſible, theſe obſtructions. In the common pump theſe impediments are great; becauſe the ſurface of the valve, which is expoſed to the air underneath, is generally very ſmall; and the vacancy between the piſton and the bottom of the barrel bears a greater proportion to the whole barrel than it would if the work were properly executed.

Theſe imperfections Mr. *Smeaton* conſidered and endeavoured to remove in the conſtruction of his pump. For this purpoſe he expoſed a much larger ſurface of the lower valve to the air underneath, by forming a kind of grating in the plate. By this the coheſion was leſſened, and more power could apply to open the valve in the firſt inſtant. The difficulty ariſing from the air retained in the barrel he removed, in a great meaſure, by making the piſton fit more nicely to the bottom, and by taking the weight of the atmoſphere from off the piſton, which allowed the valve in it to be more eaſily opened, ſo that much more of the air could paſs through it. The weight of the atmoſphere he removed from the piſton, by cloſing the top of the barrel with a plate, on which he fixed a collar of leathers; through this the cylindrical part of the piſton-rod moves air-tight. And the air, having paſſed through the piſton, is forced out of the barrel through a hole in the top-plate, over which is a valve to prevent the return of air, when the piſton deſcends. The piſton is made to fit as exactly to the top, as to the bottom of the barrel, to exclude the air more effectually.

By this improvement, Mr. *Smeaton* ſays, "I have been able to "rarefy the air one thouſand times, when the pump was put

" clean together; and that it ſeldom failed of doing it five hun-
" dred, after it had been uſed for ſeveral months without clean-
" ing: whereas the degree of rarefaction produced by the beſt
" common pumps never exceeded one hundred and forty times,
" when tried by my gage."

I have taken up much of your time in this account; but I hope you will not think unneceſſarily, as it ſhows the ground on which I have gone, and a deſcription of Mr. *Smeaton's* pump is, in ſome meaſure, a deſcription of mine.

Mr. *Smeaton* having done ſo much to facilitate the opening of the valves, at the bottom of the barrel, and in the piſton, by which means he carried the degree of rarefaction much further than the common pump could do; I ſuppoſed, if thoſe valves were entirely removed, and the remaining air in the barrel could be more perfectly expelled, the rarefaction might be carried ſtill further. Upon this plan I have conſtructed my pump. I have removed the lower valve, and opened the bottom of the barrel into a ciſtern, on which it is placed, and which has a free communication with the receiver. For the valve on the plate, at the top of the barrel, (which is conſtructed like Mr. *Smeaton's*) makes it unneceſſary there ſhould be any at the bottom, in order to rarefy the air in the receiver.

The ciſtern is deep enough to allow the piſton to deſcend into it, below the bottom of the barrel. Suppoſe then the piſton to be ſolid; that is, without a valve in it; when it enters the barrel and riſes to the top plate, which is made air-tight with a collar of leathers, &c. like Mr. *Smeaton's*, it forces out all the air above it; and as the air cannot return into the barrel, on account of the valve on the top-plate, when the piſton deſcends there will be a vacuum formed between that and the plate;

plate; every thing being ſuppoſed perfect. But in working the pump, the piſton is not allowed to deſcend entirely into the ciſtern, ſo far as to leave the bottom of the barrel open; becauſe, as the ciſtern, for another purpoſe, is made larger than the bore of the barrel, this might make the piſton-rod work unſteadily in the collar of leathers, and cauſe it to leak: but it deſcends below a hole in the ſide of the barrel, near the bottom, which opens a free communication between the barrel, ciſtern, and receiver. Through this hole the air ruſhes from the ciſtern into the exhauſted barrel, when the piſton has dropped below it; and by its next aſcent this air is forced out as the other was before. If now the capacity of the receiver, ciſtern, pipes, &c. below the bottom of the barrel, taken together, be equal to the capacity of the barrel, half the remaining air will be expelled by every ſtroke.

But as the working a pump of this kind, with a ſolid piſton, would be laborious, on account of the reſiſtance it would meet with in its deſcent from the air beneath; (though this would be leſſened by every ſtroke, as the air became more rarefied) I have, to remedy this inconvenience, pierced three holes in the piſton, at equal diſtances from each other; and a circular piece of bladder, which is tied over the top of the piſton, to make the joint more perfect with the top-plate, and to defend them from injury when the piſton is brought up againſt it, forms a kind of valve over the holes, which opens eaſy enough to prevent any labour in working the pump, as it allows the air to paſs through the piſton when it deſcends. But the air does not neceſſarily depend upon a paſſage through the piſton in order to get into the barrel: for when the air becomes ſo weak, from its rarefaction, that it cannot open this valve, it will ſtill get into the barrel.

rel when the communication is opened by the hole at the bottom. This piſton, therefore, will deſcend as eaſy as any other; and this valve does not impede the rarefaction; ſince it is of no conſequence, as to this, whether it open or not. By this conſtruction, the valves, which Mr. *Smeaton* only made to open with more eaſe, are rendered unneceſſary in rarefying the air: and that at the bottom of the barrel, which is the moſt difficult to be made and kept in order, is entirely removed; that on the top-plate being the only one neceſſary in rarefying the air.

But as in a ſingle barrelled pump of this conſtruction, where there is no valve at the bottom to prevent the air, which follows up the piſton in its aſcent, from returning into the receiver in its deſcent, a fluctuation would be produced, which might prove detrimental in ſome experiments, this pump is made with two barrels, which rarefies the air at every ſtroke of the winch. In this conſtruction, the capacity of the two barrels, taken together, below the piſtons, is always the ſame; for while one is deſcending, the other is aſcending; and what is taken from the one is added to the other.

Having thus ſet aſide the valves, which in ſome meaſure prevented the air from getting into the barrel and above the piſton, I next attempted to expel the air more perfectly out of the barrel than Mr. *Smeaton* has done, by making a better vacuum between the piſton and the top-plate, which would allow more of the air to expand itſelf into the barrel from the receiver. But to ſhow in what manner I have attempted this, it will be neceſſary to give ſome further deſcription of the machine.

I have, upon Mr. *Smeaton's* plan, contrived to connect the valves on the top-plates with the receiver, occaſionally, by means

means of a pipe and cock, by the turning of which, the machine may be made to exhauſt or condenſe at pleaſure. This is done in the following manner: There is a croſs-piece laid over the valves, extending from one barrel to the other, which has a duct through it, connected with a ſmall pipe ſtanding between the barrels: through this pipe the air paſſes into a duct in the bottom-piece leading to the cock. In this piece is likewiſe the duct leading from the ciſtern to the cock; and with this cock alſo is connected the pipe leading to the receiver. The key is pierced with two holes in ſuch a manner, that one of them will connect the pipe coming from the receiver with the duct in the bottom-piece leading to the ciſtern, or with the other leading to the valves, as may be required for exhauſting, or condenſing. The other hole through the key will open, occaſionally, to the atmoſphere, either of theſe ducts round the cock. So that having the direction of the air which paſſes through the valves, under the command of this cock, the pump may exhauſt or condenſe at pleaſure: for when the key connects the pipe from the receiver, and the duct leading to the ciſterns together, the pump will exhauſt; and when it connects the pipe with the duct leading to the valves, it will condenſe; as the other hole in the key, at the ſame time, opens to the atmoſphere the duct leading to the ciſterns, by which paſſage the air enters the barrel from the atmoſphere, is forced out at the valves, and through the pipe and cock into the receiver. In this part of the machine which is contrived for condenſation, I have, by an additional part, endeavoured to get the air more perfectly out of the barrel.

We have ſeen that Mr. *Smeaton*, by making the piſton of his pump fit more exactly to the bottom of the barrel, and by ſhutting

ſhutting up the top to prevent the preſſure of the atmoſphere on the piſton-valve, was able to get more of the air above it than could be effected in the common pump. But ſtill the difficulty, though ſo far removed, remains in the top of the barrel: for as the piſton cannot be made to fit ſo exactly to the top-plate, but that there will be ſome lodgment for air, it is impoſſible to expel it entirely; more, perhaps, might be expelled if the valve on the top could be made to open more eaſily, by removing the weight of the air from it; for the atmoſphere, preſſing on this valve, will prevent its opening freely, in the ſame manner as when preſſing on the piſton-valve, it obſtructs the opening of that in the common pump.

The difficulty which Mr. *Smeaton* removed from the piſton-valves, I have endeavoured to remove from the valve on the top-plate; that this valve, having the preſſure of the atmoſphere taken off, might open with the ſame eaſe as the piſton-valve does in his pump. To effect this, there is connected with the duct on the bottom-piece, which conveys the air from the valves to the cock, a ſmall pump of the ſame conſtruction as the large one; having the barrel opening into a ciſtern, the piſton-rod moving through a collar of leathers, and a valve near the top, through which the air is forced into the atmoſphere. This piſton is ſolid; becauſe the diameter, being only half-inch, does not make it work hard. This pump, which is of one barrel only, I call the valve-pump; its chief uſe being to rarefy the air above the valves, or remove the weight of the atmoſphere from off them. To uſe this pump, it is neceſſary the key of the cock ſhould be pierced differently from that of Mr. *Smeaton's*; for as the pipes round his are placed at equal diſtances, when the one from the bottom of the barrel is connected

with

with that from the receiver to exhauſt it, the other, from the valve on the top-plate, is opened to the atmoſphere by the other paſſage through the cock. But in order to rarefy the air above the valve in my pump, it is neceſſary this laſt paſſage ſhould be ſhut up, when the valve-pump is uſed. Inſtead, therefore, of placing the three ducts at equal diſtances round the cock, I have divided the whole into five equal parts; leaving the diſtance of one-fifth between the ducts leading from the ciſtern and the valves to the cock, and two-fifths between each of theſe and the one leading from the cock to the receiver. By this adjuſtment, when the communication is open between the receiver and valves, for condenſation, the other hole through the cock opens the ciſterns to the atmoſphere: but when the communication is made between the ciſterns and the receiver, for exhauſtion, a ſolid part of the key comes againſt the duct leading to the valves, and ſhuts it up; and the air, which is forced out of the barrel, paſſes into the atmoſphere through the valve-pump; for the valve of the ſmall pump may be kept open while the great one is worked.

Now, to apply Mr. *Smeaton's* reaſoning to this conſtruction. After mentioning his taking off the weight of the atmoſphere from the piſton, by ſhutting up the top of the barrel, he ſays, "The conſequence of this conſtruction is, that when the piſ-"ton is put down to the bottom of the cylinder, the air in the "lodgement under the piſton will evacuate itſelf ſo much the "more, as the valve of the piſton opens more eaſily, when "preſſed by the rarefied air above it, than when preſſed by the "whole weight of the atmoſphere. Hence, as the piſton may "be made to fit as nearly to the top of the cylinder, as it can to "the bottom, the air may be rarefied as much above the piſton

" as it could before have been in the receiver. It follows, " therefore, that the air may now be rarefied in the receiver, " in duplicate proportion of what it could be upon the com- " mon principle; every thing elſe being ſuppoſed perfect." The ſame may be ſaid with regard to the valve on the top-plate in this machine. It will open more eaſily, when preſſed by the rarefied air above it, than when preſſed by the weight of the whole atmoſphere. Hence, as by the conſtruction of the valve-pump the air may be rarefied as much above the valves, as it could before have been in the barrel and receiver, with which there is a free communication: it therefore follows, that the air may now be rarefied in the receiver in duplicate proportion of what it could be by Mr. *Smeaton's* pump; every thing elſe being ſuppoſed perfect; and the nature of the air permitting it.

In this eſtimation, any advantage which may ariſe from the removal of the valves at the bottom of the barrels and in the piſton, is not conſidered: But if they made any reſiſtance in Mr. *Smeaton's* pump, may we not conclude, that the rarefaction might be carried further by a machine wherein no ſuch valves are made uſe of? Mr. *Smeaton* ſays, that when he contrived to open his valves by the winch, independent of the ſpring of air, he did not find it anſwer the purpoſe better than when the air was the agent. There is no reaſoning againſt experiment: but it certainly appears probable from theory, that there muſt be conſiderable reſiſtance from the valves when the air is greatly rarefied.

He afterwards ſays, " the degree, to which I have been able " to rarefy the air, by experiment, has generally been about one " thouſand times, when the pump is put clean together: but " the

" the moiſture that adheres to the inſide of the barrel, as well " as the other internal parts, upon letting in the air, is, in the " ſame ſucceeding trials, worked together with the oil, which " ſoon renders it ſo clammy as to obſtruct the action of the " pump, upon a fluid ſo ſubtle as the air is, when ſo much " expanded.—But in this caſe it ſeldom fails to act upon the " air in the receiver, till it is expanded five hundred times; and " this I have found it to do, after being frequently uſed for ſeveral " months without cleaning." Does it not appear probable, that this clammineſs muſt have a bad effect upon the valves, as well as the other internal parts of the pump, in thoſe ſame ſucceeding trials? and that the ſtiffneſs which the oil acquires by evaporation, the corroſion of the braſs, &c. when the pump is foul, muſt greatly obſtruct the opening of the valves, and bear a principle part in reducing the rarefaction from one thouſand to five hundred times?

I ſuppoſed the valves to be a great obſtruction, and have endeavoured to avoid them: and if no further advantage be derived from it, the machine is more ſimple without them.

Upon this conſtruction, alſo, we are able to make the pump with two barrels, like the common pump, which cannot be done conveniently where the lower valve is retained; becauſe it would be difficult to make the piſton in one barrel come exactly to the bottom, at the ſame time that the piſton in the other touched as exactly at the top: it would, at leaſt, require a nicety in the workmanſhip, which would be troubleſome to execute.

In this pump, the piſtons do not move the whole length of the barrels: there is a horizontal ſection made in them, a little more than half way from the bottom, where the top-plates are

inſerted. By this mean the pump is made more convenient and ſimple, as the head of it is brought down upon the top of the barrels, in the ſame manner as in the common air-pump. The barrels alſo ſtand upon the ſame plane with the receiver-plate; and this plane is raiſed high enough to admit the common gage of thirty-two or three inches, to ſtand under it, without any inconvenience in working the pump, as the winch moves thro' *a leſs* portion of an arch, at each ſtroke, than it would if the piſtons moved the whole length of the barrels.

There is alſo placed, between the barrels in this pump, on the croſs-piece over the valves, a gage to meaſure the degree of condenſation, having a free communication with the valves, cock, &c. This gage is ſo conſtructed, that it will alſo ſerve to meaſure the rarefaction above the valves, when the air is worked off by the valve-pump. It conſiſts of a pedeſtal, which forms a ciſtern for the mercury, a hollow braſs pillar, and glaſs tube, hermetically ſealed at one end, which moves up and down in the pillar, through a collar of leathers. The dye of the pedeſtal is made of glaſs, as well to hold the quick-ſilver, as to expoſe its ſurface to view, that it may be ſeen when the open end of the tube is put down into it, or raiſed out of it. The body of the pillar is partly cut away to expoſe the tube to view in the ſame manner.

If the pump be uſed as a condenſer, the degree of condenſation is ſhown by a ſcale marked on one edge of the pillar: if it be uſed as an exhauſter, the degree of the rarefaction of the air, above the valves, is ſhown by a ſcale marked on the other edge of the pillar.

This gage will alſo ſerve to ſhow when the valves have done playing, either with the weight of the atmoſphere on them,

or

or taken off. If we want to know when they ceaſe opening, with the weight of the atmoſphere on them, draw the piſton of the valve-pump up into its barrel, to prevent any air eſcaping through that valve; in this ſituation, work the great pump again, and if any air paſſes through the valves into the pipe, the gage will riſe by condenſation. This condenſed air muſt then be let out by opening the communication, at the cock, with the outward air. By repeating this till the gage riſes no longer, we may know the valves will open no more while the weight of the atmoſphere lies on them; and the rarefaction in the receiver can be carried no further. When the weight of the atmoſphere is to be removed, after conducting as in the former experiment, raiſe the open end of the tube above the ſurface of the mercury, and then work the valve-pump, and the air will be rarefied over the valves, and in the tube, to the ſame degree: (we may ſee when the valve of this pump has done playing by unſcrewing the cap that covers it.) The open end of the tube is then to be immerſed into the mercury, and the great pump worked. The air which paſſes thro' the valves will then raiſe the gage by condenſation: and thus, by alternately raiſing and depreſſing the tube, and working the two pumps in their turns, we may carry the rarefaction of the air in the receiver as far as the power of the pump will go. If one of Mr. *Smeaton's* pear-gages be uſed in the receiver, as he directs, the difference of the rarefaction, in the two experiments, may be known. And as the air above the valves may be rarefied to different degrees, we may know, by the two gages, what proportion the rarefaction above the valves bears to the degree of exceſs in the receiver. This condenſing gage can be taken off, and a button ſcrewed into the hole in its ſtead, in any caſe wherein a greater degree of condenſation is required than the

the glaſs will bear. When a glaſs receiver is uſed, this gage may be placed within it, where it will meaſure any degree of condenſation the receiver will bear, without danger to the gage: or the capacity of any receiver may be meaſured by this gage, before it is removed from its place, by ſhowing how many ſtrokes of the winch will throw one atmoſphere into the receiver; then turning the cock, to prevent any air eſcaping, change the gage for the button: when this is done, the degree of condenſation may be further meaſured by the number of ſtrokes.

As in caſes where great condenſation is required, there muſt be a great deal of labour, and a great ſtrain on the teeth of the wheel and piſton-rods, on account of the great diameter of the piſtons; * to remedy this, I have fitted a condenſer, of a ſmaller bore than the barrel of the great pump, to the ciſtern of the valve-pump, to be ſcrewed on occaſionally; by which the condenſation may be finiſhed, inſtead of the great pump. Or, to ſave the work and expence of this condenſer, the valve-pump, if made a little larger, may be eaſily fitted for the ſame purpoſe, by having a plate made to ſcrew into the bottom of the cylinder, occaſionally, with a valve on it, opening into the ciſtern: a hole muſt alſo be made to be opened, on the ſame occaſion, near the top of the cylinder, to let air in below the piſton, when this is drawn up above it.

The common gage, which is generally placed under the receiver-plate, in this pump, is placed in the front; that it may be ſeen by the perſon who is working the pump, and that the plate may be left free for other uſes.

The

* In my pump, the piſtons are two inches diameter; ſo that there will be about forty-eight pounds added to the reſiſtance in opening the valves, for every atmoſphere thrown into the receiver.

The plate is ſo fixed to the pipe, leading to the cock, that it may be taken off at pleaſure, and uſed as a transferer; or any tube, or apparatus, may be fixed to it, to perform ſome experiments without removing it, which will ſave trouble, and make leſs apparatus neceſſary.

The head of this pump is not divided, as the common one is, to diſlodge the teeth of the wheel from the piſton-rods, when the pump is to be taken apart; but is made whole, except a ſmall piece in the back, where the wheel is let in; which makes it much more convenient to remove the head, or place it on the barrels. The wheel is freed from the piſton-rods, when required, by puſhing it into the back part of the head; and when it is drawn into its place and connected with them again, a button is ſcrewed into the ſocket of the axis behind, to keep it in its place. This makes the head leſs troubleſome to remove: but its chief uſe is to diſlodge the piſton-rods from the wheel, that they may be put down into the ciſterns, when the pump is not in uſe, where they will ſtand uncompreſſed, and retain their elaſticity better than if kept in the barrels. In theſe ciſterns they may alſo ſtand covered with oil, if neceſſary, as they are large enough to admit of it.

The principal joints of the pump are ſunk in ſockets, that the leathers, which cloſe them, may be covered with oil, to prevent leaking.*

For convenience, the lower part of the pump is fitted with drawers, to contain the apparatus. A door opens behind one range

* This, I find, is very effectual; having never known one of the joints, ſecured in this way, to leak, though the pump has ſtood for a long time: whereas a portable pump which I have, made by Mr. *Nairne*, *London*, has leaked, and repeatedly been refitted with new-oiled leathers, in the ſame time.

range, to a place reſerved the whole height, to get at the under part of the receiver-plate, and fix apparatus to it for ſome experiments. In this place ſtand the long tubes, and ſuch tall glaſſes, belonging to the apparatus, as will not go into the drawers. The barrels, &c. of the pump are covered with a caſe, or head, which keeps them from duſt and accidents, when the pump is not in uſe. The apparatus is ſecured between ſliders, &c. in the drawers, ſo that the whole machine may be eaſily removed, in one body, without danger.

HAving given you this account of the machine, I wiſh, Sir, I could add to it, at this time, the reſult by experiment, and inform you to what degree it will rarefy the air; but the want of a proper apparatus to meaſure the rarefaction, prevents me.

As we have no glaſs-manufactory here, I ſent to *Europe* for my apparatus, about twelve months ſince: but, unluckily, this part, with ſome others, have not yet been forwarded to me. As ſoon as I can ſatisfy myſelf, I will let you know the reſult. I have, at preſent, only a ſmall tube of two-tenths inch bore, I accidentally met with, which I uſe as a common gage: but this will not determine the power of the pump.

All I can ſay of the inſtrument at preſent is, that I find it much more convenient to uſe than one of the common ſort: that it will exhauſt a receiver much ſooner, and keep in order much longer, for being made without valves, which muſt depend on the ſpring of the air to open them. When a common pump, which I have, has been fitted up with valves, leathers, &c. at the ſame time with this; the valves of the common pump have become too dry and ſtiff to uſe, while this pump has continued in good order. I attribute this, in part, to the moiſture which the valves on the top-plates receive from the

piſtons

piſtons every time the pump is uſed; the piſtons being always kept moiſtened with oil in the ciſterns, where they ſtand when the pump is not in uſe; and in part, to the power which the piſtons have over theſe valves, by condenſing the air againſt them. In the common pump, and in Mr. *Smeaton's*, the valves, at the bottom of the barrels, can only be opened by the ſpring of the air acting againſt them: but in this pump the valves are forced open, by raiſing the piſtons, and muſt, therefore, yield much longer to the power applied in this way.

I mentioned above, that the piſtons in this pump did not move the whole length of the barrels; but were interrupted by the plate, a little more than half way from the bottom, for convenience: but on this conſtruction, they may be made to move through the whole length, as in Mr. *Smeaton's* pump; and then it will exhauſt a receiver in half the time that his will, if the capacity of each barrel in the two pumps be equal. And perhaps the air may be further rarefied by a pump on this conſtruction without the valves, whoſe barrels are of greater length than the barrels of my pump. For ſince the piſton may be made to fit as well to the top of one barrel as another, if the length of the barrel, through which the piſton moves, be twelve inches inſtead of ſix, the vacancy, which is unavoidably left between the top-plate and the piſton, when the latter is drawn up to the former, will bear a leſs proportion to the capacity of the whole barrel. Suppoſe, then, the valve on the top-plate will riſe only till the air be expanded one hundred times in a barrel of ſix inches length, becauſe this is the proportion which the vacancy bears to the capacity of the whole barrel, (the reſiſtance of the valve not being taken into the account) it will riſe till the air is expanded two hundred times in a barrel of twelve inches

length, the diameters being the ſame in both, becauſe the capacity of the barrel being doubled, the vacancy bears ſo much leſs proportion to it than to one of ſix inches. And if the air can be rarefied in proportion to the difference between the vacancy and the capacity of the barrel, by leſſening this proportion, which, after having made the work to fit as well as poſſible, is to be done by enlarging the capacity of the barrel, the power of the pump muſt be increaſed.

This, Sir, is reaſoning from theory: but theſe circumſtances, I think, ought to be conſidered in the conſtruction of an air-pump; and experiment only muſt determine how far an attention to them may be uſeful.

The rarefaction which a pump will produce, by experiment, may come very far ſhort of what it ought to do by the theory of its conſtruction. If the common pump will, in experiment, rarefy the air only one hundred times, when in its beſt ſtate, and Mr. *Smeaton's*, by conſtruction, in duplicate proportion to this, it ought to go to ten thouſand; every thing being ſuppoſed perfect: but in its beſt ſtate, Mr. *Smeaton's* pump will only rarefy the air about one thouſand times; ſo that the nine-tenths which it falls ſhort of what it ought to do by theory, is to be attributed either to the imperfection of the machine alone, or to the nature of the air, in not permitting the rarefaction to go further than one thouſand times, or both theſe cauſes together. The way to prove how far this is owing to the air itſelf, is by making a machine, which, in theory, will carry the rarefaction further. A pump conſtructed without the valves, as mine is, ought to rarefy the air in duplicate proportion of what Mr. *Smeaton's* ſhould do by theory, and in quadruplicate proportion of the common pump, which would be one hundred million,

allowing

allowing the common one to rarefy the air one hundred times. Nothing like this, however, is to be expected, ſince we ſee Mr. *Smeaton's* pump, in experiment, falls ſo far ſhort of the theory. But ſuppoſing my pump to rarefy the air in duplicate proportion of what Mr. *Smeaton's* does by experiment, this would carry the rarefaction to one million times: and whatever it falls ſhort of this, muſt be attributed either to the imperfection of the machine, or the nature of the air, or both together: or if this pump ſhould rarefy the air only to the ſame degree with Mr. *Smeaton's*, ſince by conſtruction it ought to go ſo much further, will it not aſcertain to us, in a direct line, that the nature of the air does not admit of being further rarefied by a pump; and that this is the reaſon why Mr. *Smeaton's* pump, in experiment, fell ſo far ſhort of the theory? If this ſhould be the caſe, will it not be a confirmation that the power of mechaniſm is not wanting to produce a much greater rarefaction in the receiver, where no body acts immediately upon the air to expel it, and from which place it can only be induced to come, by making room for its expanſion into ſome other? I hope, in a little time, to be able to inform you what the reſult is by experiment, and to what degree this pump will exhauſt the receiver.

I am, &c.

JOHN PRINCE.

NOTE. Since this letter was communicated, I have ſeen, in the 67th vol. of the Philoſophical Tranſactions, an account of ſome experiments made by Mr. *Nairne*, with a pump conſtructed on Mr. *Smeaton's* principle: from which it appears that Mr. *Smeaton* was deceived with reſpect to the rarefaction in his receiver, as indicated by the pear-gage; and that the greateſt power of the pump, when the experiment was properly made, would carry the rarefaction in the receiver only to ſix hundred, inſtead of

AN EXPLANATION OF THE PLATES.

PLATE IV. Fig. 1. A view of the pump ſhut up, when not in uſe; appearing through a glaſs window, as ſhewn by the pricked lines.

Fig. 2. A view of the pump when opened and uncovered for experiments.

Fig. 3 A perpendicular ſection of one of the barrels, the two ciſterns, condenſing gage, &c. where A B repreſents the barrel: C D the ciſtern on which it ſtands; *a a a a* the leathered joint, ſunk into a ſocket, and buried in oil: E F is the piſton; the cylindrical rod paſſing through a collar of leathers, G G, in the box H I. K ſhows the place of the valve on the top-plate K L, covered by the croſs-piece M M, into which the pipe O O is ſoldered; that conveys the air from the valves to the duct going under the valve-pump, as may be ſeen in plate V. fig. 1. *o* is part of the ſaid duct; *p* is the joint ſunk into a ſocket in the croſs-piece P P, which connects the ciſterns and has a duct through it leading to them. Into this duct open the ducts *q* and *r*, the firſt leading to the gage in front of the pump, the other to the cock and receiver.

of one thouſand times. By an account of Mr. *Cowallo's*, in the 73d vol. of the Philoſophical Tranſactions, I find an improvement made in Mr. *Smeaton's* pump, by Mr. *Haas*, inſtrument-maker. He has contrived to open the valve at the bottom of the barrel independent of the ſpring of the air underneath; and by this improvement he has increaſed the power of the pump to one thouſand times. This experiment is a confirmation of what is to be expected from the removal of the valve in my pump, which is done with greater ſimplicity, as Mr. *Haas's* contrivance is complex, conſiſting of a ring lying at the bottom of the barrel, to which ring the valve is faſtened; this ring is raiſed by a pedal, connected with two wires moving through two collars of leathers, and is depreſſed by a ſpiral ſpring contained in a ſocket, the whole being fixed under the barrel of the pump: But he has done nothing to remove the reſiſtance from the valve in the piſton, nor the weight of the atmoſphere from off the valve on the top-plate.

The other barrel is left out of the figure, to ſhow ſome of the parts more diſtinctly; except Q Q, which is the top of the barrel retained and brought down out of its place, to ſhow the top-plate, that ſhuts up the barrel, ſeparated from the box, which contains the collar of leathers. S ſhows one of the holes in the plate over which the valve lies, and which is covered by R in the croſs-piece. V V is the piſton ſhowing the valve open on the top, which is to prevent labour when the pump condenſes. W X is the ciſtern, in which is more diſtinctly ſeen the ſhoulder for the leather which cloſes the joint between this and the barrel, and alſo the ſocket in which the oil lies over the leather. Y Z is the condenſing gage, with the orifice of the tube raiſed above the ſurface of the quick-ſilver. *e e* is the collar of leathers, through which the glaſs tube moves. *i* is a ſmall pipe coming up through the quick-ſilver to make a communication between the valves and the gage.

Fig. 4. is a view of the upper ſurface of the top-plate which cloſes the barrel, being ſoldered into it, ſhowing the place of the valve over the three ſmall holes, one of which only can be ſeen at S, in fig. 3.

Plate V. fig. 1. is a perpendicular ſection of the bottom-piece, pipes, valve-pump, cock, &c. at right angles with the other ſection, fig. 3. pl. IV. A B is the pipe between the barrels, as repreſented in plate IV. The button *o* is here ſcrewed into the top inſtead of the gage. C D is the valve-pump and its ciſtern, *e* the place of the valve under the cap. E F the cock, ſhowing the duct through it leading to the atmoſphere. G H the pipe leading from it to the ſtem of the receiver-plate, in which is the cock I, to ſhut up the duct when the plate is uſed as a transferer. K K is the plate. L a piece to ſhut up

the

the hole into which tubes, &c. are occaſionally ſcrewed to perform experiments without removing the plate: the pricked line at O ſhows the place of the ſcrew which preſſes the plate againſt the pipe: P Q the pipe and common gage ſtanding in front of the pump.

Fig. 2. is a horizontal ſection of the cock and pieces, containing the ducts leading from it to the receiver, the ciſterns, and the valves on the top of the barrels. A B the duct connecting the ciſterns together. C D the duct leading from the ciſterns to the cock. G H the duct leading from the cock, through the pipe A B, (fig. 1.) to the valves. D E the duct through the cock, which occaſionally connects the two laſt-mentioned ducts with the duct E F, leading from the cock to the receiver. I the duct in the cock leading to the atmoſphere, which, when connected with the duct at D, lets the air into the ciſterns and barrels for condenſation; the other duct through the cock at the ſame time connecting H and E. This duct alſo, when connected with E, reſtores the equilibrium in the receiver. K L is part of the duct leading from the ciſterns to the gage. The pricked circles ſhow the places of the pipe and valve-pump on the piece, and *r* the place where the air enters the valve-pump from the duct G H, and is thrown into the atmoſphere, when the pump exhauſts.

Fig. 3. ſhows the under ſurface of the boxes, which contain the collars of leathers, with the croſs-piece, which connects them together, having a duct through it, as repreſented by the pricked line, through which the air paſſes from the valves to the pipe: this fig. is deſigned chiefly to ſhow the places in which the valves play, as at I.

Fig.

Fig. 4. is a ſide view of the pump, ſhowing the ſituation of the valve-pump and handle of the cock; where A is the pump, and B the handle.

Fig. 5. is the top-plate which ſcrews the key of the cock into its ſhell, and keeps it tight: the upper ſurface of it is marked with directions to turn the key ſo as to produce the effect deſired: for when the mark on the key agrees with the mark on the plate, the pump exhauſts, and ſo of the reſt.